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AN AEROLOGICAL SURVEY OF THE UNITED STATES.[1]

PART I. RESULTS OF OBSERVATIONS BY MEANS OF KITES.

By WILLIS RAY GREGG, Meteorologist.

[Author's Abstract.]

Aerological investigations by means of kites, pilot and sounding balloons have been carried on by the Weather Bureau for several years. In addition, there is available a large amount of similar data secured by the Blue Hill Observatory and by the meteorological services of the War and Navy Departments. Although the material at hand is not sufficient for a *final* analysis of the results, it nevertheless seems appropriate to summarize and publish such results as we have as soon as possible after they are obtained in order that they may be available for the information and use of those most interested in them. Subsequent revisions, although of some importance in that they furnish results of greater precision, will hardly affect the practical value of these data which are so much needed at the present time, particularly in connection with aviation and ordnance. To meet this need there is being prepared a series of summaries under the general heading "An Aerological Survey of the United States." The first part, just issued and the subject of this abstract, gives the results of observations by means of kites. It contains, in addition to the discussion, numerous figures and tables from which can be obtained detailed information as to the characteristics of the free air over the United States east of the Rocky Mountains. Much of this detailed information will necessarily be of interest only to those to whom it is vital, principally aviators, and the edition is therefore a limited one. To many others a briefer, more general review, giving the main results, will be sufficient. The present abstract or review endeavors to supply this more general need.

For the most part the results are based upon observations with kites at the six stations established by the Weather Bureau during the period 1915 to 1918, but in Figures 2 to 4 mean values have been used as determined from observations at Mount Weather, Va., and Blue Hill Observatory, Mass., in order to give as complete a picture as possible of free-air conditions over the eastern and central portions of the United States. The stations, their geographic coordinates, and the periods of observation are given in Table 1.

Station.	Altitude, m. s. l.	Latitude, N.	Longitude, W.	Period of observation (inclusive).	
				From—	To—
	m.	° ′	° ′		
Broken Arrow, Okla	233	36 02	95 49	Aug. 1918	Dec., 1920
Drexel, Nebr	396	41 20	96 16	Oct., 1915	Do.
Ellendale, N. Dak	444	45 59	98 34	Jan., 1918	Do.
Groesbeck, Tex	141	31 30	96 28	Oct., 1918	Do.
Leesburg, Ga	85	31 47	84 14	Mar., 1919	June, 1920
Royal Center, Ind	225	40 53	86 29	July 1918	Dec. 1920
Blue Hill, Mass	195	42 13	71 07	1896	1903
Mount Weather, Va	526	39 04	77 53	July, 1907	June, 1912

In the original paper a series of tables gives for the stations listed in Table 1, except Blue Hill and Mount Weather, the mean monthly, seasonal, and annual barometric and vapor pressures in mb.; temperatures in degrees centigrade; relative humidities in percentages; densities in kg. per cu. m. and in percentages of standard (standard = 1.293 kg. per cu. m.); and wind resultants in degrees and m. p. s. Mean seasonal values of temperature, relative humidity, and vapor pressure are shown also in three figures. In this abstract the tables and two of the figures are omitted. Figure 1 shows the mean seasonal free-air temperatures at the six stations. Conspicuous features brought out by these data are the decided permanent inversion of temperature in the lower levels at northwestern stations during the winter; the large latitudinal difference in annual temperature range, both surface and free-air; the small annual range in relative humidity at the northern stations, but the large range, with highest in summer, at the southern stations; and the substantial agreement in the annual range of vapor pressure at all stations, this range of course becoming very small in the higher levels.

Some of the original data are presented in somewhat different form in Figures 2 to 4, inclusive. Each figure consists of 12 small outline maps of the United States, representing different levels and showing for those levels the mean summer and winter values of pressure, temperature, and resultant wind. In order to make these maps as complete as possible for the eastern and central portions of the country, there have been included the mean values at Blue Hill, Mass., and Mount Weather, Va., each based upon a long series of observations made with kites several years ago. The values for Blue Hill have been taken from Clayton's study of the diurnal and annual periods of temperature, humidity, etc.[2] In that publication only the mean temperatures and relative humidities are given, but with these data it has been possible to compute the mean pressures (barometric and vapor) and the mean densities. In order to test the accuracy of these computed values, similar computations were made for all other stations and then compared with the means as determined from the individual observations themselves. In all cases the agreement was strikingly close. The values for Mount Weather have been taken from a previous paper.[3] Neither at Blue Hill nor at Mount Weather were the observations of wind summarized in such form as to make possible the determination of wind resultants. The wind charts are therefore not as complete as are those for the other elements.

[1] MONTHLY WEATHER REVIEW SUPPLEMENT, No. 20, pp. 78, figs. 25. Washington, D. C., 1922.

[2] Clayton, H. H. *Annals of the Astronomical Observatory of Harvard College.* Vol. LVIII, Pt. I, p. 59. 1904.

[3] Mean values of free-air barometric and vapor pressures, temperatures, and densities over the United States. By W. R. Gregg. MONTHLY WEATHER REVIEW, January, 1918. 46:11-20.

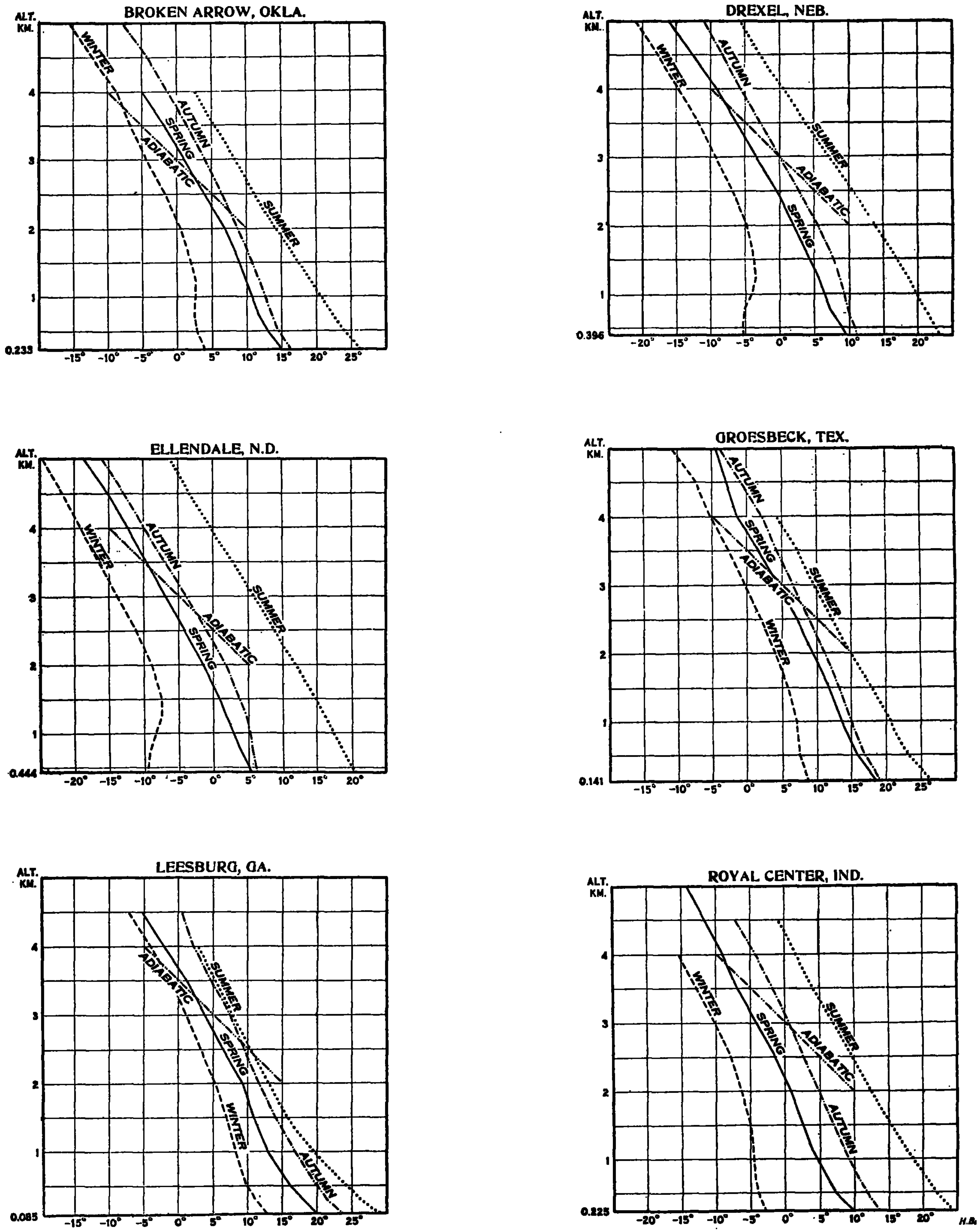

FIG. 1.—Mean seasonal free-air temperatures, °C.

The figures are published in such a way that the contrast between summer and winter conditions may be seen at a glance. Thus, the summer and winter mean barometric pressures, respectively, appear side by side on the same page, in Figure 2. The same arrangement holds for the other elements. All contain, in addition to the iso-lines, the locations of the stations and the mean values for those stations.

An examination of these charts, and others not published here, brings out the following points:

1. The large difference between summer and winter conditions at all levels and at all latitudes.

2. The substantial parallelism in the lines of equal pressure and temperature at all levels. This is to be expected since, as is well known, the pressure at any given level is largely a function of the temperature of the air beneath that level.

3. The slight southward trend of isobars and isotherms in the upper levels from the interior to the eastern portions of the country. In this connection it is interesting to note that in winter this trend of the isotherms in the upper levels is the opposite of that at and near the surface. In other words, on the same parallels of latitude, except in the Southern States, the air from the surface to about 1 kilometer above it is warmer in the East than in the Middle West but considerably colder at greater altitudes. As is well known, cyclonic storms in this country, no matter where they originate, pass out as a rule across or near the New England States. These storms are most frequent and intense in winter and, because of the almost continuous procession of them through the Northeast, produce a resultant low pressure in that section. To some extent, then, the lower free-air temperatures in the East are due to dynamic cooling, but the differences are too great to be accounted for wholly in this way. They are probably due in large part to the following circumstance: Many of the cyclones referred to originate in the South or Southwest, and these usually intensify as they travel, becoming storms of marked vigor by the time they have passed into the Atlantic. During the time that they are near or off the coast the pressure gradient westward is steep, resulting in strong northerly and northwesterly winds which bring in large masses of very cold air. Clayton, as the result of his studies of Blue Hill data, states [4] that "with increase of height the temperature falls more rapidly in the rear of the cyclone than it increases in front." The frequency with which this condition occurs is in all likelihood largely responsible for the lower mean free-air temperatures in the Northeast than at the same latitudes in the Middle West. To a less extent this is true also for summer, when it applies to all levels, even the surface. In the winter, however, as already stated, the reverse is found at and near the surface, i. e., the Middle West is much colder than the East, a condition which is readily explained by the frequent occurrence of anticyclonic weather, with its clear skies and intense radiation. This is distinctly a characteristic feature of continental climate, and that it is purely a surface phenomenon is evident from the pronounced temperature inversions that are almost invariably found and whose magnitudes are such as to produce a resultant inversion even in the mean values for the entire season, as is well shown in Figure 1. Occasionally a rapid succession of HIGHS passing over a given place tends to a gradual thickening of the stratum of cold air and the consequent disappearance of the temperature inversion. Notable instances occurred during the cold winter of 1917–18. Such cases are, however, exceptions to the rule.[5]

4. The higher relative humidity in the South than in the North during summer and the opposite gradient during winter, owing in all probability to the more pronounced convectional activity in the South during summer and to the greater storminess in the North during winter.

5. The close agreement in the summer and winter latitudinal range of vapor pressure at all altitudes. This is largely explained by the circumstance that, although the latitudinal temperature range is much greater in winter than in summer, yet, on the other hand, the change in vapor pressure is much less for a given change in temperature when the latter is in general low than when it is high, the relation between temperature and vapor pressure being logarithmic, not linear. Another contributing cause of the similarity in the latitudinal range of vapor pressure during summer and winter is the fact that the relative humidity diminishes northward during summer, thus adding to the relatively small effect of the moderate temperature range, but diminishes *southward* during winter thus acting against the relatively large effect of the steep temperature gradient in that season.

6. The small latitudinal density gradient in the higher levels, owing to the counterbalancing effects of pressure and temperature, i. e., density varies directly with pressure; inversely with temperature. It is also worthy of note that the annual range diminishes markedly with altitude. Observations at greater heights would undoubtedly show practically the same values in all parts of the country and throughout the year at about the 8-kilometer level.[6] The question of standard density, or a "standard atmosphere," is receiving considerable attention at present in connection with aviation and with the firing of projectiles. This subject has been discussed at some length in the original paper and also in a Special Report, No. 147, issued by the National Advisory Committee for Aeronautics. It is thought unnecessary, therefore, to make further reference to it here.

7. The small latitudinal difference in resultant wind speeds, due to the fact that these vary directly with the pressure gradient, but *inversely* with the sine of the latitude. An exception is to be noted in the case of the southern stations in summer, but it should be borne in mind that that region is not during the summer under the control of the prevailing westerlies, but rather that of the "horse latitudes." Winds are light and variable, and a longer record is necessary for the determination of true resultant values. With this exception the arrows in the charts show a very close relation to the mean pressure gradients. In general at all altitudes there is a southerly component in summer and a northerly in winter. A further examination of these charts, together with a study of Bowie and Weightman's work on the movement of cyclones,[7] brings out a fact of considerable significance. From the data given in Table 2, page 8, of that work it is possible to compute the average summer and winter rates of movement of all storms. The resulting values are, respectively, 9.3 and 13.4. Reference to Figure 4 shows that these rates of movement are in striking agreement with the resultant wind speeds at 3 to 4 kilometers,

[4] The distribution of the meteorological elements around cyclones and anticyclones up to 3 kilometers at Blue Hill. By H. H. Clayton. *Annals of the Astronomical Observatory of Harvard College.* Vol. LXVIII, Pt. I. 1909.

[5] For further discussion of this subject the reader is referred to: Some observations on temperatures and winds at moderate elevations above the ground. By V. E. Jakl. MONTHLY WEATHER REVIEW, June, 1919, 47:367–373. Of particular interest are Figures 1, 3, and 4 and accompanying text.

[6] See: Level of constant air density. By W. J. Humphreys. MONTHLY WEATHER REVIEW, May, 1921, 49:280–281.

[7] Types of storms of the United States and their average movements. By E. H. Bowie and R. H. Weightman. MONTHLY WEATHER REVIEW SUPPLEMENT NO. 1, 1914.

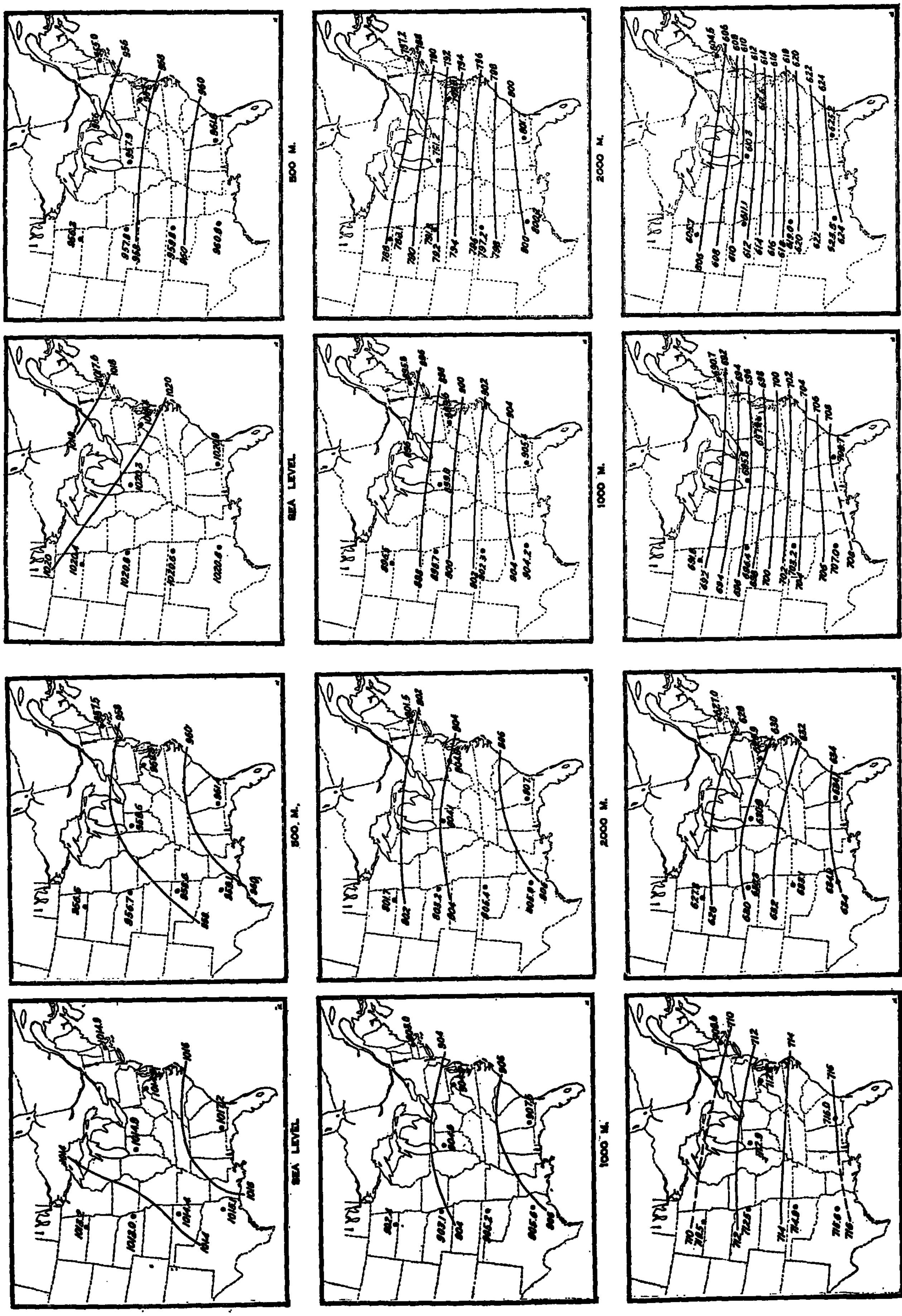

FIG. 2.—Mean summer and winter barometric pressures, mb, respectively, at specified levels over the eastern and central portions of the United States. Summer at left, winter at right.

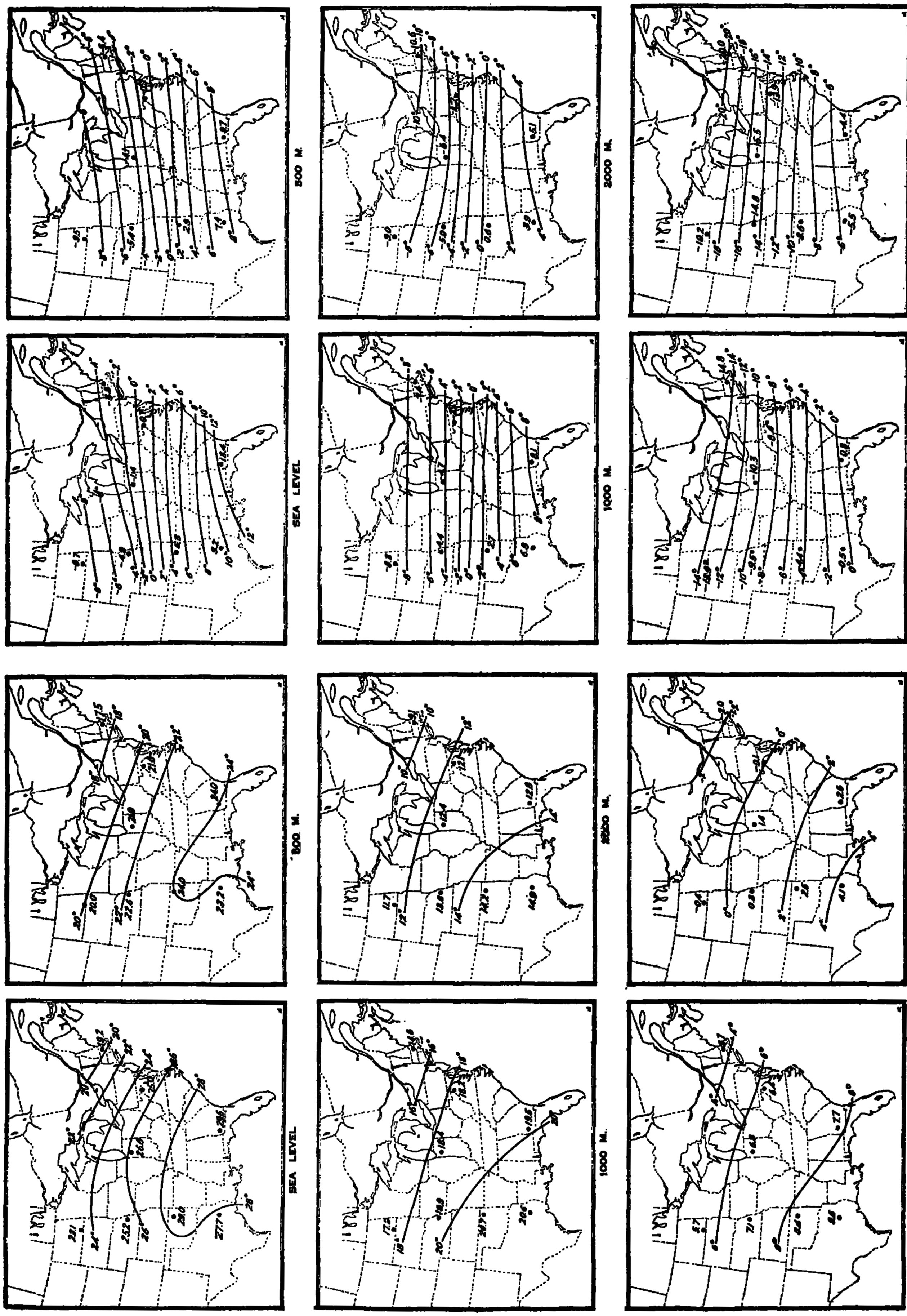

FIG. 3.—Mean summer and winter temperatures, (°C.) respectively, at specified levels over the eastern and central portions of the United States. Summer at left, winter at right.

the altitude with best agreement being higher in summer than in winter. This close agreement is in line with the belief of most meteorologists that the movements of storms are largely controlled by the air circulation prevailing at altitudes of 3 to 5 kilometers.

FREE-AIR DATA: WINDS.

Wind resultants are shown in Figure 4 and have already been discussed. For many purposes a knowledge of these is of interest, as, for example, in studies of the general atmospheric circulation, including the movements of cyclones and anticyclones, etc. They also give information of value in connection with the laying out of a permanent flying course or "airway," or, in the event that a choice of routes is impracticable, they assist in the determination of operating costs by showing the amount of head winds, cross winds, etc., which on the average will be encountered. It is apparent, however, that in practical aviation wind resultants have at best limited application. There is need for an accurate knowledge of the behavior of free-air winds under different conditions of wind and weather at the earth's surface. The following discussion attempts to fill this need so far as it can be filled with the data thus far accumulated.

All observations have been classified according to wind direction at the surface. In obtaining mean values the directions and velocities have been considered independently, whereas the resultant winds, Figure 4, have been determined by first resolving each observation into its north and west components. In addition to the mean values for each surface direction there have been determined the average deviation, average velocity increase with altitude, and the average percentage frequency of winds from different directions, of clockwise and counterclockwise turning, and west and north components in the winds at various heights. Briefly, the results are as follows:

Average deviation.—Near the surface the turning of the winds is generally to the right, no matter what the surface direction may be. This turning is most pronounced with southerly surface winds, i. e., east through south to west-southwest, until at 3 to 4 kilometers it amounts on the average to somewhat more than 90°. With northerly winds, on the other hand, i. e., west-northwest through north to northeast or east-northeast, the turning is to the right but small in amount up to about 1 kilometer, and then changes to the left at higher levels. The deviation is greater in winter than in summer at all stations and is also greater at northern than at southern stations. In other words, the turning is most pronounced when and where the latitudinal temperature gradient is strongest and hence the prevailing westerlies best developed. It is to be noted that in general the amount of the deviation in the upper levels varies directly, or nearly so, as the angle between the surface direction and a westerly direction. For example, a surface southeasterly wind turns more than does a surface southerly wind—both becoming as a rule southwesterly or west-southwesterly in the upper levels.

Average velocity increase.—In the lower levels up to an altitude of about 1 kilometer the largest increases in velocity occur above surface southeasterly to southwesterly winds, but at greater heights, i. e., 1½ to 4 kilometers (and presumably thence up to the base of the stratosphere) the largest increases are found above surface southwesterly to northwesterly winds. They are least in all seasons and at all heights above surface northeasterly to east-southeasterly winds.

Average actual directions and velocities.—The seasonal variation in surface velocities is small; there is also little variation in surface velocities with direction, i. e., easterly winds are nearly as strong as are westerly winds; above the surface all winds increase in speed up to an altitude of about 500 meters; on the average this increase amounts to about 100 per cent, but it is greater above westerly than above easterly winds; at still higher levels easterly winds diminish, but westerly winds continue to increase; coincident with these changes in free-air wind velocities there is a turning of the winds such that they approach very nearly a westerly direction, except that above northeasterly to easterly surface winds there is generally an east component up to at least the 4-kilometer level; and the seasonal variation, slight at the surface, increases rapidly with altitude at both the northern and southern stations.

The seasonal means for all directions are shown in Figure 5. The more prominent features are: The large increase in velocity in the first 500 meters above the surface; a more gradual increase at greater heights (in summer there is an actual decrease—most pronounced at southern stations); the decided seasonal variation in the upper levels; the seasonal lag, i. e., higher velocities in spring than in autumn; and the close approach to a westerly direction in the higher levels, this feature being most in evidence at the northern stations.

Frequency of free-air winds from different directions.—Values for summer and winter at selected levels are shown in Figures 6 to 8. For convenience in contrasting summer and winter conditions the figures for those seasons at the selected levels appear side by side on the same page. Following these are given in Figure 9 the conditions at 3 and 4 kilometers for the year. Arcs represent 5 per cent intervals.

The more striking features are: (1) The greater percentage of easterly winds at all levels in summer than in winter; (2) the pronounced south component in summer, especially at southern stations, and the equally pronounced north component in winter, especially at northern stations; (3) the resulting predominance of a south component at southern stations and of a north component at northern stations for the year; and (4) the very large west component at all stations for the year at 3 and 4 kilometers.

Clockwise and counterclockwise turning.—The tendency to clockwise turning is greater than that to counterclockwise for all directions near the surface but is most pronounced for southerly winds, i. e., east through south to west-southwest; this tendency increases with altitude for these southerly winds and amounts to about 90 per cent at 3 to 4 kilometers; with northerly winds the tendency to clockwise turning does not change much with altitude, but the tendency to counterclockwise turning, small near the surface, increases to 60 to 80 per cent at 3 to 4 kilometers; and the turning is more pronounced, especially near the surface, in winter than in summer and at northern than at southern stations.

West component.—An inspection of the tabulated data showed at once that above surface westerly winds, i. e., north-northwest to south-southwest, there is a west component in practically all cases. When the remaining directions are considered, it is found that at heights of 3 to 4 kilometers a west component is more frequent than an east component, except for surface winds from northeast to east. Above these winds a west component occurs in about 25 to 30 per cent of the cases. Taking *all* surface directions, we find in the upper levels a striking preponderance of a west over an east component, the

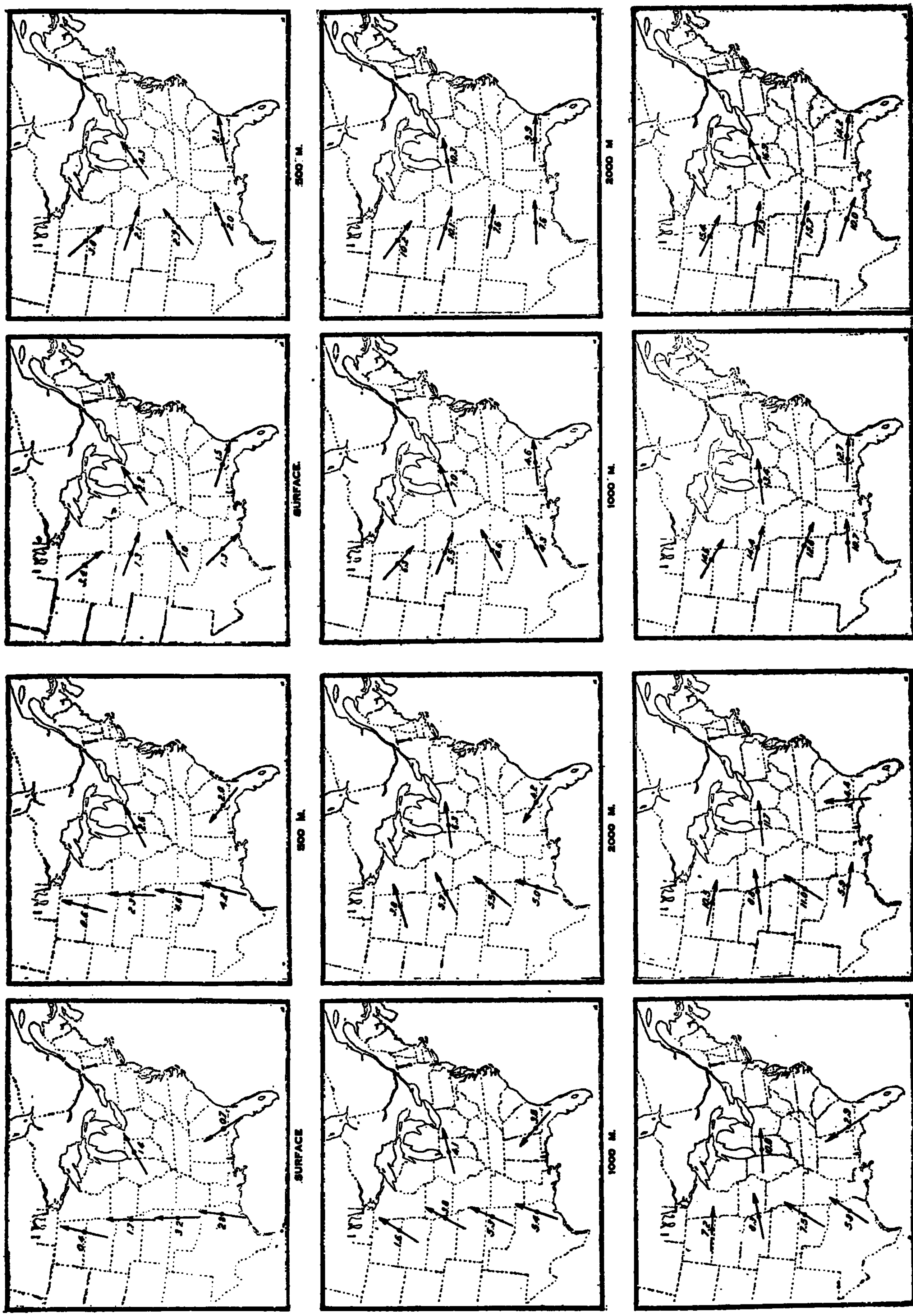

FIG. 4.—Mean summer and winter wind resultants, m. p. s., respectively, at specified levels over the eastern and central portions of the United States. Summer at left, winter at right.

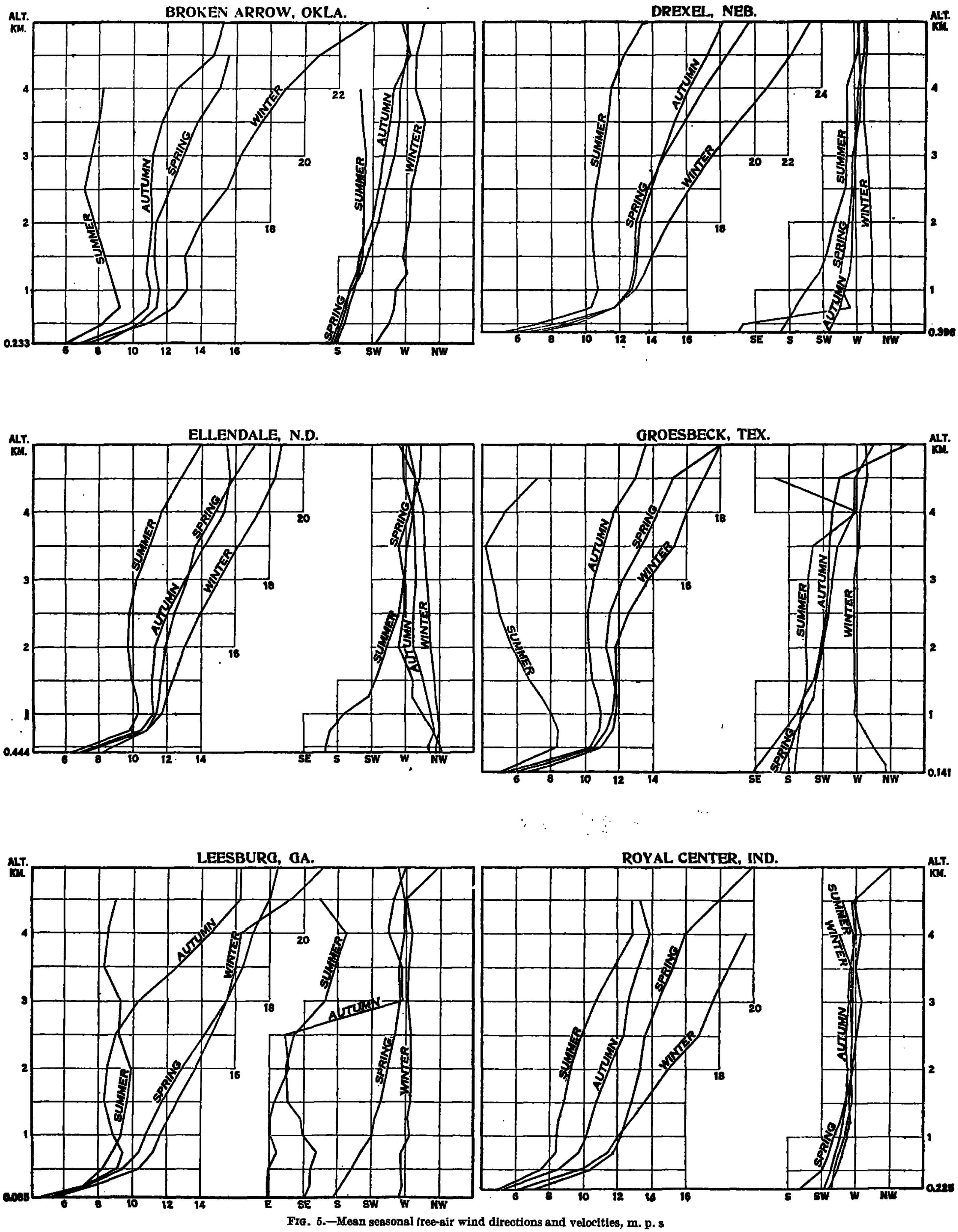

FIG. 5.—Mean seasonal free-air wind directions and velocities, m. p. s

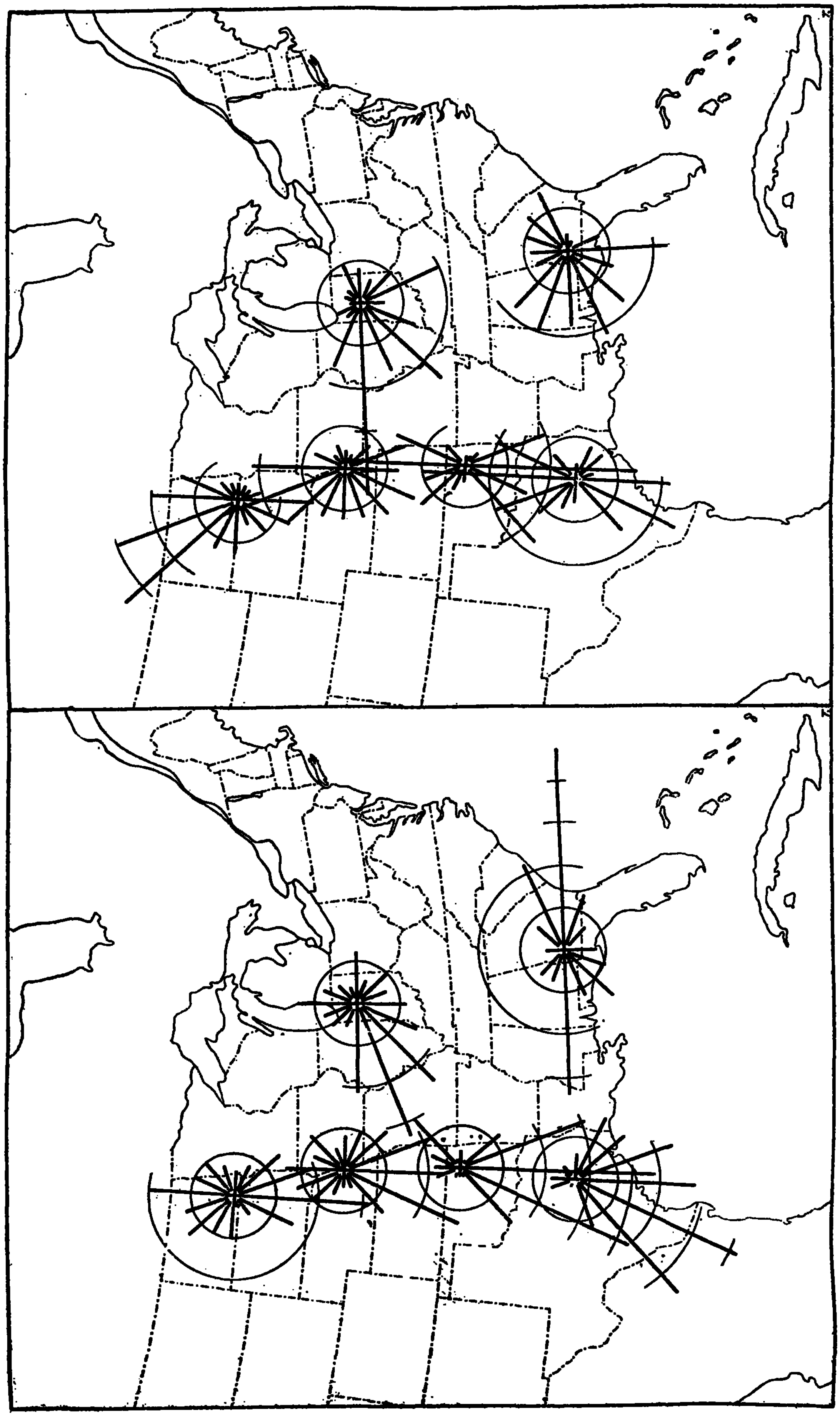

Fig. 6.—Percentage frequency of winds from different directions at the surface. Summer at left, winter at right.

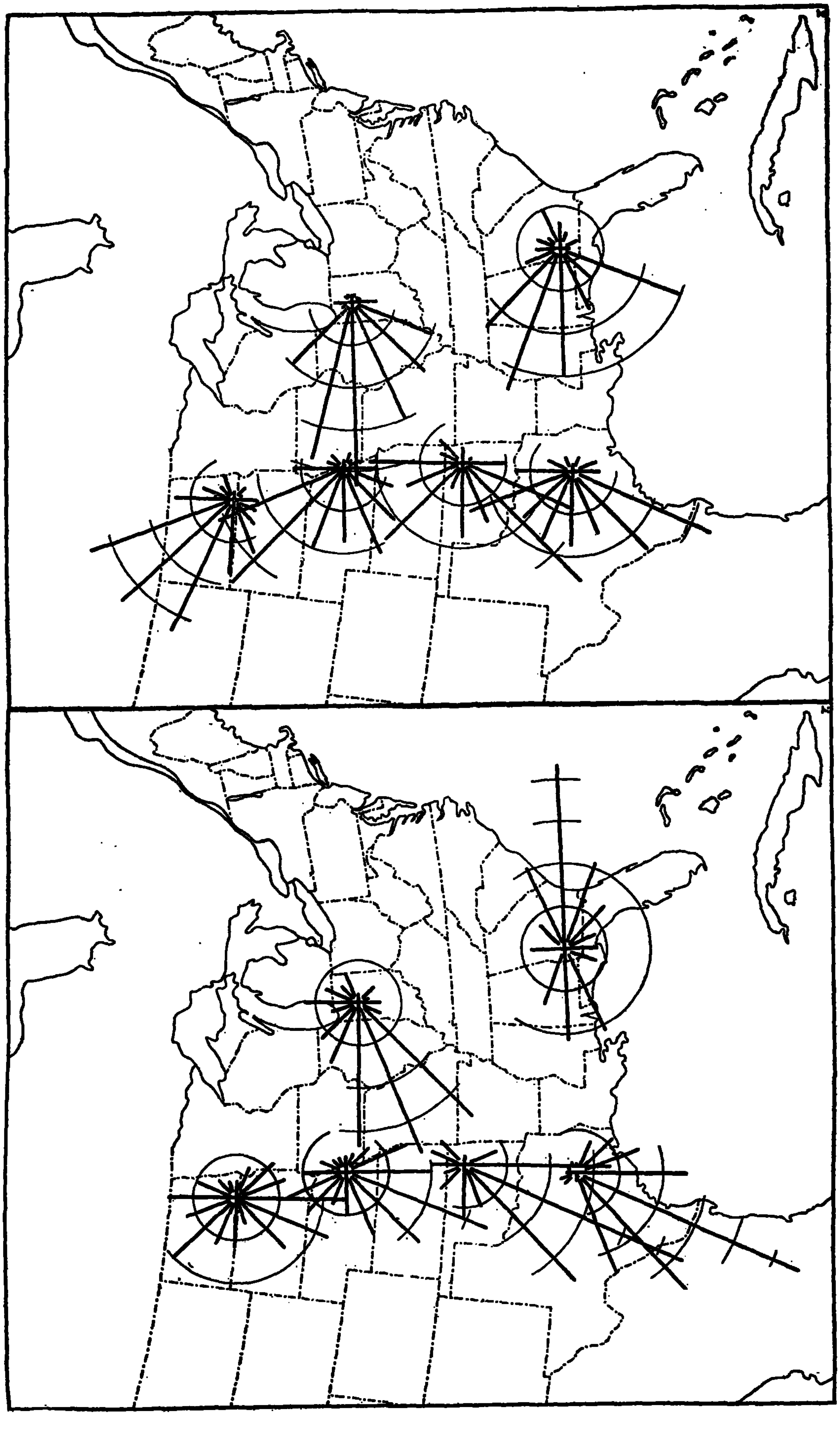

FIG. 7.—Percentage frequency of winds from different directions at 1,500 m. Summer at left, winter at right.

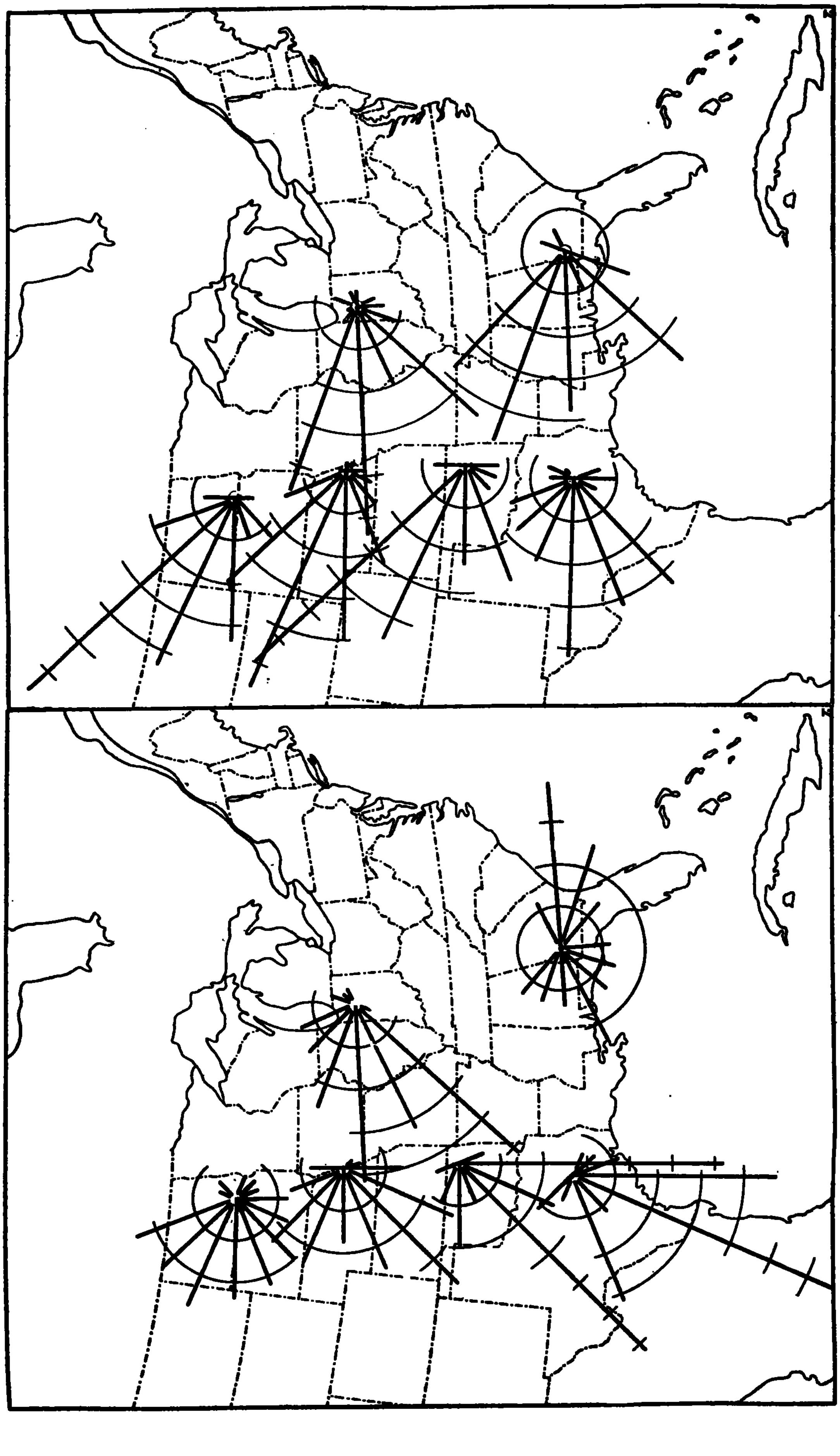

FIG. 8.—Percentage frequency of winds from different directions at 3,000 m. Summer at left, winter at right.

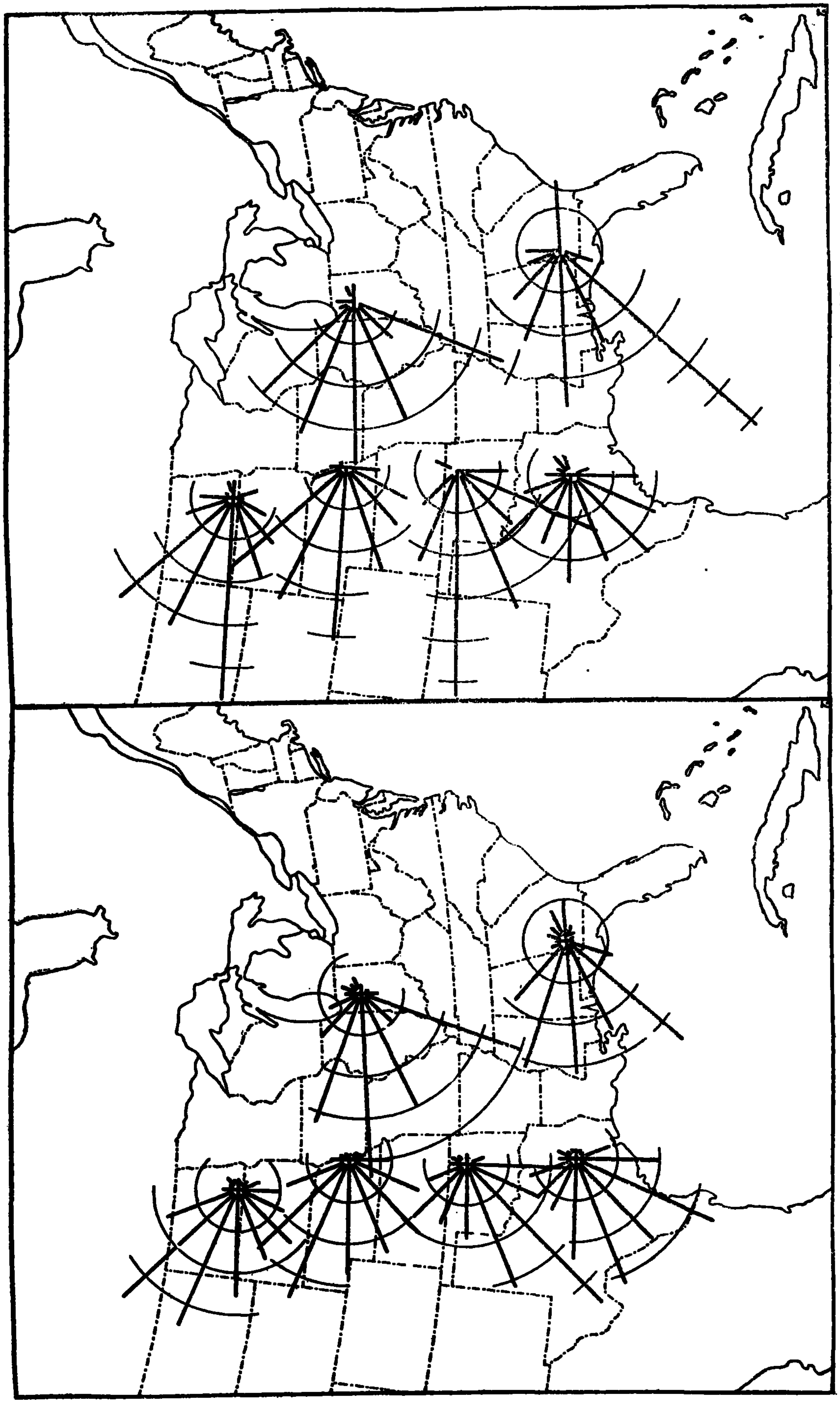

FIG. 9.—Percentage frequency of winds (annual) from different directions at 3,000 m. and 4,000 m., the former at left, the latter at right.

annual values being 89 per cent at 3 and 94 per cent at 4 kilometers. This percentage is somewhat greater in winter than in summer and at northern than at southern stations.

North component.—The data indicate that a north or south component in the surface winds persists in a majority of cases in the upper levels, except that above a surface east-northeasterly wind a south component is the more frequent and above a southwesterly or a west-southwesterly wind a north component predominates. Other features are the pronounced south component in summer, especially at southern stations, the equally pronounced north component in winter, especially at northern stations, and the resulting predominance of a south component at southern stations and of a north component at northern stations for the year.

General remarks.—The foregoing discussion of wind data and the conclusions given should be accepted with the reservation that they are based upon observations that were made only under conditions favorable for kite flying, i. e., surface winds ranging from 2 to 20 m. p. s. and upper winds ranging from 5 to 35 m. p. s. Thus it will be seen that conditions closely approaching a calm are not represented. In other words, data are lacking for days on which there was no appreciable pressure gradient. This explains the somewhat higher velocities and the slightly larger percentage frequency of a west component given in this summary than in a previous study based upon observations with pilot balloons.[8] It should be remembered, though, that pilot balloons are observed to best advantage in light winds, since they soon disappear in the distance when winds are strong. Moreover, they can not be observed at all in clouds, whereas kite flights are frequently made in cloudy weather and occasionally even when light rain or snow is falling. All things considered, then, it seems that the results obtained with kites come nearer representing all conditions than do those with balloons. In any event, they are certainly representative of the conditions that prevail most of the time, viz, moderate winds in both clear and cloudy weather.

[8] Reihle, J. A. Flying weather in the Southern Plains States. MONTHLY WEATHER REVIEW, November, 1920, 48:627-632.

RELATION BETWEEN RATE OF MOVEMENT OF ANTICYCLONES AND THE DIRECTION AND VELOCITY OF WINDS ALOFT (WEST AND SOUTHWEST OF HIGHEST PRESSURE).

By CHARLES L. MITCHELL.

[Weather Bureau, Washington, D. C., April 25, 1922.]

The importance of anticyclones in the control of weather conditions and the desirability of accurate knowledge as to whether they will move rapidly or slowly or remain practically stationary has long been recognized by forecasters. The surface conditions as shown on the daily weather maps do not always supply all the data necessary for making accurate predictions of the movement of anticyclones. It has been evident from a day-to-day inspection of the charts of wind direction and velocity at the several levels above the earth's surface at the various aerological stations of the Weather Bureau, the Army, and the Navy that the action of anticyclones depends to a large extent on the conditions shown at 2,000 to 4,000 meters, or even higher, above sea level. A study has been made, therefore, of the aerological charts of wind direction and speed in free air from pilot balloon flights from the time their preparation was begun in October, 1920, to the end of March, 1922, in connection with the rate of movement of anticyclones. In all, 62 anticyclones over the eastern half of the United States were studied, and they were classified (1) as to place of first appearance on the weather map, and (2) in relation to free-air wind direction and velocity at or above 2,000 meters to the west and southwest of the crests of the anticyclones, when available. Free-air observations below the 1,000-meter level were not considered in this study.

In general, it may be said that the rate of movement of the anticyclone is roughly proportional to the speed of the free-air winds at and above the 2,000-meter level. The results of the study are shown in the table below.

TABLE 1.—*Free-air winds and anticyclonic movement.*[1]

Winds west and southwest of crest of HIGH, usually at 2 km. to 4 km.	Type of anticyclone.			Total.
	Pacific.	Alberta or Manitoba.	Hudson Bay.	
Fresh to strong SW. winds. HIGH moved rapidly east or northeast	10	15	1	26
Same, except moderate SW. wind	0	4	1	1
Moderate SW. winds in south and fresh to strong southwest in north. Axis of HIGH changed from N.-S. to NE.-SW. Barometer fell slowly in the southeast	0	10	0	10
Fresh to strong SSW. to W winds. HIGH moved eastward with normal speed	3	8	0	11
Moderate to fresh S. and SW. in north, moderate SSE. to SSW. in south. Normal speed	1	1	0	2
Strong NW. in east and SW. from Texas northward. Deep low over Newfoundland. HIGH slow mover.	0	2	1	3
W. winds in north, SW. in south. HIGH slow mover.	1	0	0	1
Gentle to moderate SE. and S. winds. HIGH very slow mover	0	1	0	1
Fresh SW. winds. HIGH of great magnitude. Slow mover	0	2	0	2
Easterly winds aloft. Stationary HIGH	1	3	1	5
Total	16	42	4	62

[1] The term "HIGH" is used throughout this table as synonymous with "anti cyclone."

In practically every case where the winds aloft were fresh to strong southwest both to the southwest and west of region of highest pressure, the anticyclone moved eastward or northeastward rapidly (in 26 instances) or at least at a normal rate of speed (in 11 instances). The only exceptions were on January 7 and March 16, 1922, when the anticyclones were of great magnitude and